MPPT CONTROL PV CHARGING SYSTEM FOR LEAD ACID BATTERY

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Technology in Electrical Engineering

By

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Department of Electrical Engineering

National Institute of Technology, Rourkela

MAY 2014Rourkela-769008, Orissa

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Under Guidance of

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CERTIFICATE

This is to certify that the Thesis Report entitled **MPPT control PV charging system for lead acid battery**submitted by Abhishek Chauhan (212EE3226) of Electrical Engineering during May 2014 at National Institute of Technology Rourkela is an authentic work by him under my supervision and guidance.

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ABSTRACT

MPPT algorithm is an important process to ensure the best utilization of the PV panels. Maximum power point tracking of solar module aiming to improve conversion efficiency of solar module. Various tracking algorithms are available for this purpose. Of these, P&O and INC is the two most extensively used tracking algorithms**.** In this design incremental conductance (INC) used extract maximum power from solar panel. This MPPT algorithm combine with battery charging loop to charge lead acid battery with different charging stages that are constant current, constant voltage and float charging. To implement these techniques required sensing of the panel voltage, panel current, battery voltage, battery current. Sensing the voltage is easy and can be made with very less cost. For current sensing standard Hall-Effect current sensor generally used in the MPPT algorithm. Simulation and experimental results of performance of the incremental conductance (INC) algorithm and battery charging loop shows that preliminary results it is expect that the charging process using the MPPT algorithm will be faster. The result shows that this charging pattern increase efficiency of power transfer comparison to other method and assure fast, safe and complete lead acid battery charging process with full SOC.

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Chapter 1

Introduction

1.1. The Need for Renewable Energy

A developing country requires more energy. Nowadays, most of the energy supplied by fossil fuels such as diesel, coal, petrol, and gas is 80% of our current energy. On top of this energy demand is expected to grow by almost half over the next two decades. Plausibly this is causing some fear that our energy resources are starting to run out, with disturbing consequences for the global economy and global quality of life. Increasing demand of energy results in two main problem climate change and energy crisis. The global energy demand increases, the energy related greenhouse gas production increases. It is a global challenge to reduce the CO2emissionand offer clean, sustainable and affordable energy.

The worldwide increasing energy demand Energy saving is one cost effective solution, but does not tackle. Renewable energy is a good option because it gives a clean and green energy, with no CO2 emission. Renewable energy is defined as energy that comes from resources which are naturally refilled on a human timescale such as sunlight, wind, rain, tides, waves and geothermal heat.

1.2. Different Source of Renewable Energy

1.2.1. Wind Energy

The wind turbine can be used to harness the energy from the airflow. Now a day's wind energy can be used from 800 kW to 6 MW of rated power. Science power output is the function of the wind speed; it rapidly increases with increase in wind speed. In recent time have led to airfoil wind turbines, which is more efficient due to better aerodynamic structure.

1.2.2. Solar Power

Solar energy is profusely available that has made it possible to harvest it and utilize it properly. Solar energy can be a standalone producing system or can be a grid connected generating unit depending on the availability of a grid nearby. Thus it can be used to produce power in rural areas where the availability of grids is very low. Solar energy is form of energy that directly available from sun and convert in to electrical energy, which is best form of energy without any climatic change and energy crisis. This conversion can be achieved with the help of PV cell or with solar power plants.

1.2.3.Small Hydropower

Hydropower energy generates power by using a dam or diversion structure to alter the natural flow of a river or other body of water. This energy can be used by conversion the water stored in dam into electrical energy using water turbines. Hydropower, as an energy supply, also provides unique benefits to an electrical system. First, when stored in large quantities in the reservoir behind a dam, it is immediately available for use when required. Second, the energy source can be rapidly adjusted to meet demand instantaneously.

1.2.4.Geothermal

Geothermal energy is available in form of thermal energy from heat stored inside the earth. In this steam produced from reservoirs of hot water found a couple of miles or more below the Earth's surface. This energy comes from the decay of radioactive nuclei with long half-lives that are embedded within the Earth, Some energy is from residual heat left over from Earths formation and rest of the energy comes from meteorite impacts.

1.3. Literature Review

Solar power is one of the renewable energy resource that will hopefully lead us away from coal dependent and petroleum dependent energy resource. The major problem with photovoltaic charging system is that the energy conversion efficiency of solar panel is poor and high cost. Solar panels themselves are quite not efficient in their ability to convert sunlight to energy. The study shows that solar panel convert 35-45% of energy incident on into electrical energy. So our aim is how to decrease the overall cost and energy conversion efficiency of solar panel. To store solar energy charging system is also require to efficiency charge battery with lesser charging time. A Maximum Power Point Tracking algorithm is required to increase the efficiency of the solar panel. MPPT is a method that compensates for that changing voltage and current characteristic of solar panel and maximum utilization of solar energy from panel. MPPT is point where power is drawn from solar panel maximum, then efficiency of solar cell will be increase. Many maximum power point tracking algorithm are developed.

The most commonly known are [1] hill-climbing, [2] fractional open circuit voltage control, [3] perturb and observe(P&O), [4] incremental conductance(INC), [5] Neural network control, [6] fuzzy control based etc. These algorithm are vary due to simplicity, effectiveness, merging speed, sensor required and cost. The most commonly algorithm based on current and voltage sensing incremental conductance (INC) and perturb and observe (P&O) is used to track maximum power point (MPP) due to its simplicity, effectiveness & merging speed.

Under abruptly change in irradiation level as MPP, changes continuously, P & O receipts it as a change in MPP due to perturbation rather than that of irradiation and sometimes ends up in calculating incorrect MPP. However this problem gets avoided by an incremental conductance method in case of the incremental conductance method algorithm takes two sample of voltage and current to calculate MPP. However, due to higher efficiency, complexity of incremental conductance algorithm. This MPPT algorithm combines with battery charging loop to charge lead acid battery with different charging stage like constant current, constant voltage, float charge. So optimal is charging pattern design to charge Lead acid battery with three different charging stages that are constant current, constant voltage and float charging. This charging pattern of battery efficiently charge battery with lesser charging time

Implementation cost of this pattern very high because both are used voltage and current sensing device. Voltage sensing directly obtain by connecting voltage divider circuit across the panel and directly apply to the microcontroller, but current sensing require current sensor connected between panel and DC-DC converter. Generally, current sensor used for MPP high efficient LEM current sensor. Due to high cost current sensor and other device make up so PV charging system cost effective. Our aim is to design charging pattern so that abstract maximum power from solar module and efficiently charge battery with lesser charging time with low implementation cost.

1.4. Motivation

Solar energy is one source of power generation that independent away from petroleum and coal dependent energy resource. The major problem with solar energy is conversion efficiency poorer and high installation cost. Research going into this area to develop the efficient control mechanism and provide better control. So the overall installation cost of photovoltaic charging system reduces. The challenging research work going on in this area motivate behind the project.

1.5. Objective

The objective of our work is to implementation MPPT control battery charging system for lead acid battery method. In this MPPT technique also combines with a battery charging loop so that battery efficiently charge with less charging time and overall cost of reduced system.

1.6. Organization of the Thesis

This thesis has been divided into six chapters. The first chapter introduction, second chapter modeling of PV cell and DC-DC converter, third chapter study of different type MPPT technique, chapter four include smart battery charging system and chapter five include conclusion and future work.

Chapter 2

Modeling of PV Module and DC-DC Converter

2.1. MODELLING OF PV MODULE

A module consist of large number of solar cell that are arrange in parallel and series to increase voltage and current level of module. The electrical equivalent circuit of solar cell is presented in Figure. 1. It consist of, series resistance, parallel resistance, diodes and light generated current source.

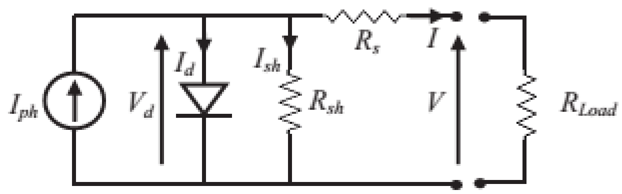

Figure 1Electrical circuit of PV module

Characteristic equation of current and voltage are modeled using Matlab Simulinkis given as fellows:-

Figure.1 show electrical circuit of PV module. From the basic theory [4] of semi-conductor V-I characteristic of ideal solar cell given below.

$$I = Iph - Isat\left[exp\frac{qV}{nKT} - 1\right] \quad \text{-------------------- (1)}$$

$$I = Iph - Isat\left[\exp\left(\frac{q(V + RsI)}{nKT}\right) - 1\right] - \frac{V + RsI}{Rsh} \quad - - - - - - - - \qquad (2)$$

where I and V denote current and voltage generated by solar module, I_{ph}(A) is current generated by solar cell when irradiating fall, I_{sat} denotes reverse saturation current of diode (A), q denotes the electrical charge =1.602*$10^{(-19)}$ C, n denotes emission coefficient of diode, K is Boltzmann's constant =1.3807*$10^{(-23)}$ $JK^{(-1)}$, T denotes temperature of solar cell in (K), R_s denotes a series resistance (Ω), and R_{sh} denotes a shunt resistance (Ω).

Basic equation (1) of ideal solar cell doesn't give I-V characteristic of practical module. Practical module consist of various component connected PV module. Practical Module require additional parameter to equation (1). Equation (2) gives single diode model of PV module shown in fig.2.

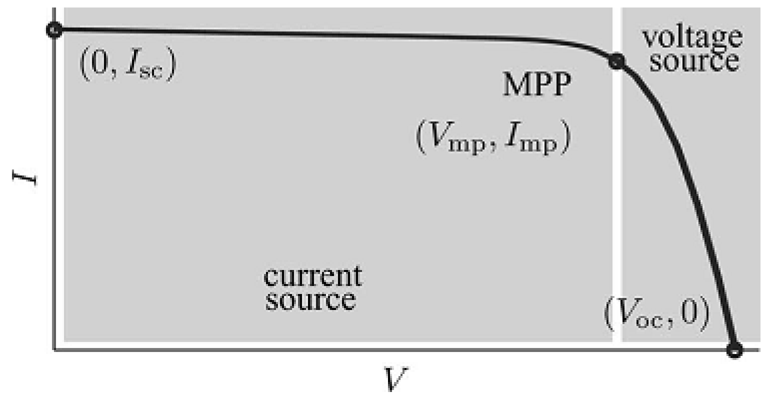

Figure 2 I-V curve of module

Equation (2) shown I-V curve of module shown in fig. 2, where three point are shown short circuit (0,Isc), MPP (Vmp,Imp) and open circuit (Voc,0). When load connected to panel change its value of voltage and current changes. I-V characteristic of module depends on temperature, irradiation and internal characteristic of module (Rs,Rsh). Light incident to module directly affect charge carrier of module so current generated by module change according to light incident to the module. When intensity of light change correspondingly temperature of module change so current generated by module also by influence temperature according to following equation.

$Iph = (Ipv + Ki * \Delta T)\frac{G}{Gt}$ --------------------- (3)

Where Gt is the nominal irradiation and G is the irradiation level on module surface.

Diode saturation equation and its dependence of temperature may expressed as

$Isat = Isat, n\left(\frac{Tn}{T}\right)^3 exp\left[\frac{qEg}{nK}\left(\frac{1}{Tn} - \frac{1}{T}\right)\right]$---------------- (4)

Where Eg is energy bad gap of semiconductor (Eg=1.12eV) for poly crystalline Si material at 25^{*}C,

Isat,n is nominal saturation current given as:

$$Isat, n = \frac{Isc}{\exp\left(\frac{Voc}{nVt}\right)-1} \text{------------------------------} (5)$$

Where Vt is thermal voltage at nominal temperature Tn.

2.1.1. I-V Characteristic

Panel Open Circuit voltage (Voc), Short Circuit Current (Isc), MPP Voltage, MPP Current and I-V characteristic with two different irradiation level are given below.

Irradiation(w/m^2)	270	580
Voc (volt)	20	20
Isc (ampere)	0.4	0.75
Vmpp (volt)	16.4	16.4
Impp (ampere)	0.35	0.66

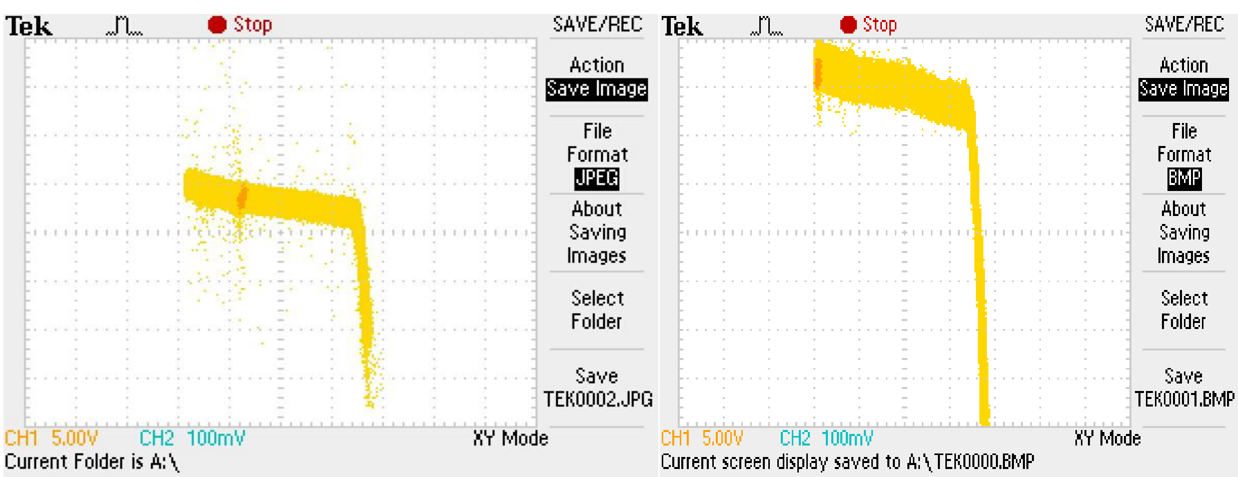

Figure 3 I-V Characteristic of irradiation level 270 w/m2 and 580 w/m2

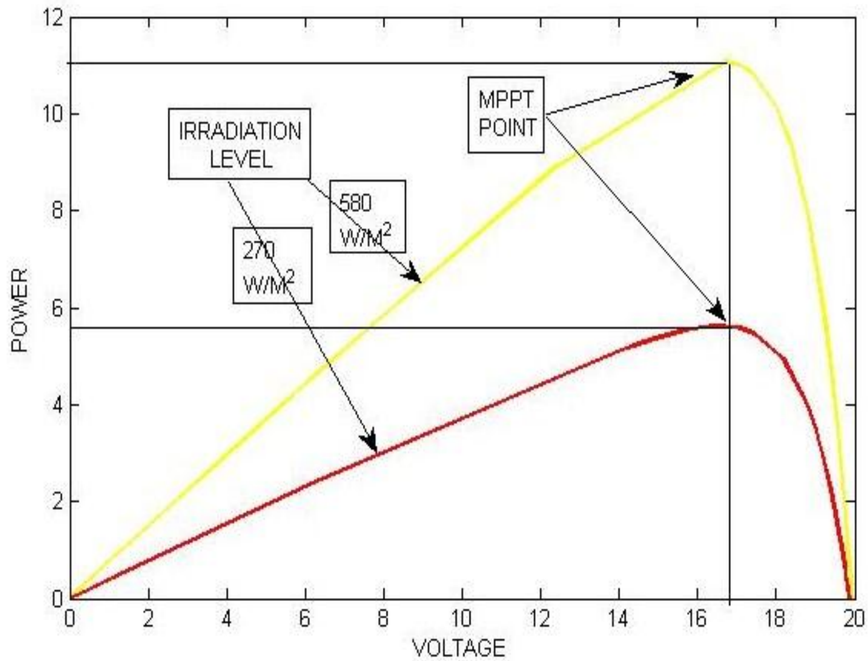

Figure 4 P-V characteristic for irradiation level 270 w/m2 and 580 w/m2

Fig. 4 gives the current–voltage (I–V) characteristics of a PV module correspondingly for two different irradiation and Fig.5 show P-V characteristic of simulated module with two irradiation level. It is seen that the output characteristics of the solar module is nonlinear and extremely pretentious by the solar irradiation, temperature and load change. To maximize power from solar module, it has to be worked at fixed value of voltage and current which is defined by manufacture, or at a definite value of load resistance. This needs DC-DC converter circuit to track maximum power from PV module or panel work at a fixed value of voltage and current. In our design, a SEPIC type DC–DC converter is used extract the maximum power from solar module by match load to PV module.

2.2. MODELLING OF SEPIC CONVERTER

DC-DC converter used in maximum power point tracking system to interface load and PV system SEPIC (Single Ended Primary Inductance Converter) is modeled, output voltage of SEPIC converter can be step-up or step-down then input voltage. In MPPT SEPIC converter work in continuous conduction mode. PWM controlled with switching frequency of 50KHz. Power flow of circuit controlled by using ON/OFF duty ratio threw switching mosfet.

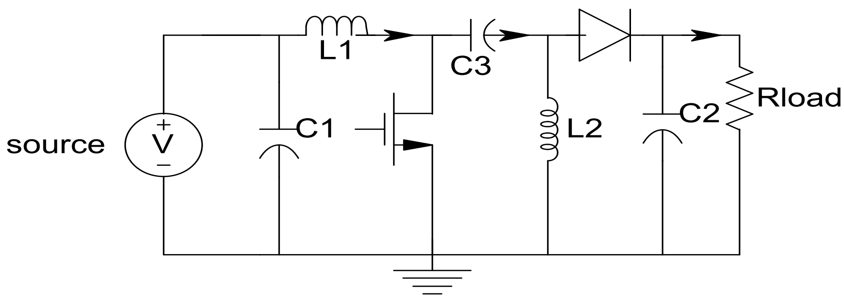

Figure 5 SEPIC converter model

SEPIC converter shown in figure.6 consist two inductor L1, L2 having same core because same voltage are applied through-out switching cycle. The capacitor C3 provide protection against short circuit load form input to output side. Two coupling capacitor C1, C2 also used to prevent DC biasing current from previous stage,

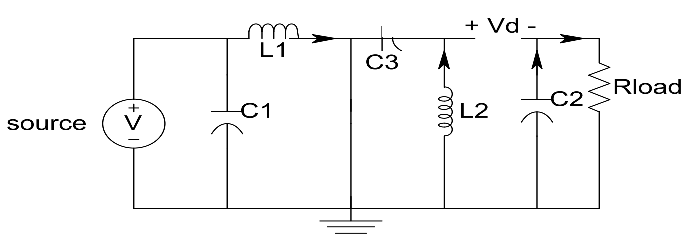

Fig. 6 (a) Current flow during on time

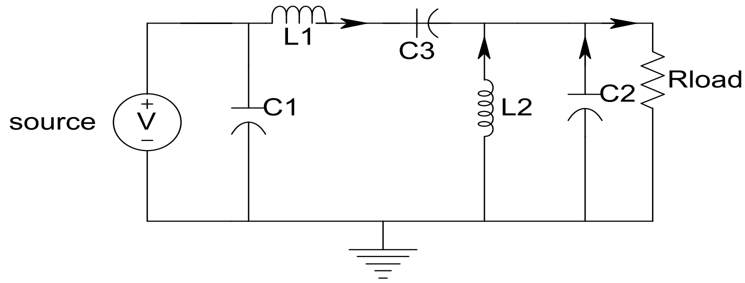

Fig. 6 (b) Current flow during off time

By Considering Characteristic of PV panel power calculation SEPIC converter designed maximum Power (P_{max}) =11W, MPPT Voltage Vmp = 16.3, MPPT current Imp = 0.67, open circuit voltage (Voc) =21 and short circuit current = 0.75. Now SEPIC converter designed with calculation value of two separate inductor L1 and L2. Design consider general working point:

Input Voltage (V_{IN}) = 12V- 17V;

Output voltage (Vout) = 12V-13V;

Switching frequency = 50 kHz

Efficiency consider=93%

To work SEPIC converter in continuous conduction mode duty cycle given as

$$\mathrm{Dmax} = \frac{\mathrm{Vout}}{\mathrm{Vout} + \mathrm{Vin}}$$

D= 12/(12+15.5) = 0.43

Inductor value calculation:

For calculation inductor value peak to peak ripple current has taken 40% of maximum input current at minimum input voltage. So peak to peak current flowing through inductor L1 and L2 given by

$$\Delta I = Iin * 40\% = Iout * \frac{Vout}{Vmin} * 40\%$$

So inductor value calculated as

$$L1 = L2 = \frac{Vin(min)}{\Delta I * f} * Dmax$$

Where Vin (min) voltage across inductor, ΔI peak to peak inductor ripple so f frequency so L1

and L2 calculated as 150µH.

Coupling capacitor calculation:

Coupling capacitor value calculation depends on rms value passing through capacitor that is given by

$$Ic3(rms) = Iout * \sqrt{\left[\frac{Vout + Vd}{Vin(min)}\right]}$$

$$\Delta Vc = \frac{Iout * Dmax}{C3 * f}$$

So value of coupling capacitor has selected this rated value of current and voltage

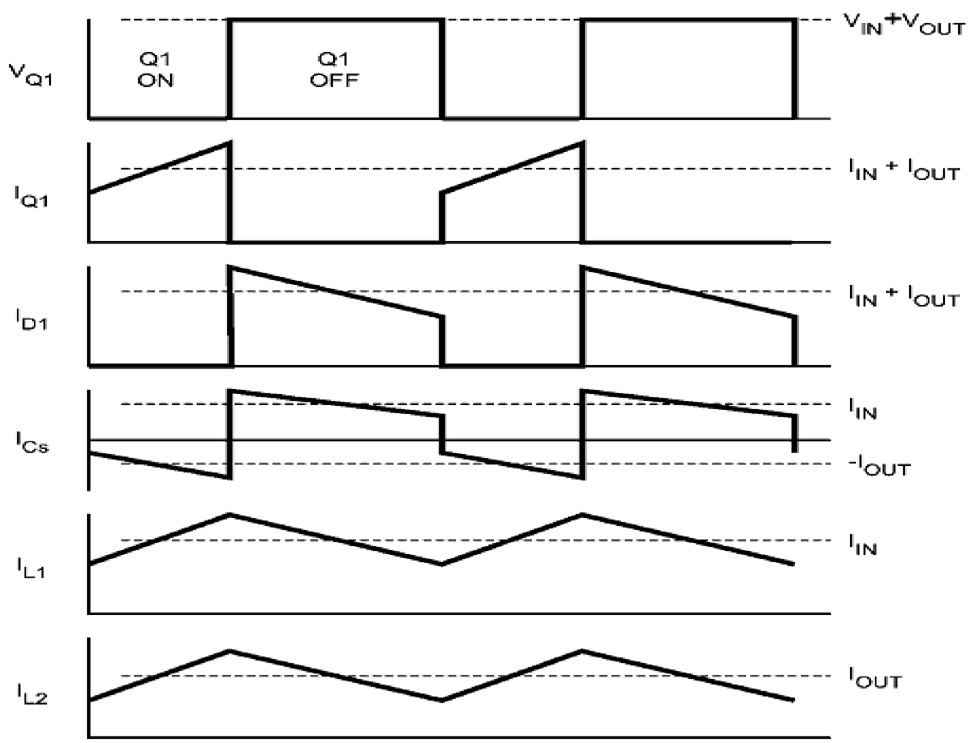

Figure 6 Charging and discharging Waveform of SEPIC Converter

In Figure. 3, the diagram of the SEPIC converter power stage is given. It contains of the power switch K IRF640 (MOSFET transistor), inductor L1, L2=0.15mH, filter capacitor C2, C1=220uF and C3=20uF, output diode D and load resistor Rload. SEPIC converter working at high frequency (50 KHz) is designed which is controlled by Arduino microcontroller. Arduino microcontroller generate PWM signal which is directly given to sepic converter to control duty cycle according to the temperature and irradiation. The Arduino microcontroller change duty ratio to maximize power output from the solar module so module working always at its MPPT point. By considering steady state operation Transfer Function is given below:-

$$\frac{Vo}{Vin} = \frac{D}{I-D} \qquad (2)$$

Where duty cycle (D) is control by Arduino Microcontroller using MPPT algorithm.

2.2.1 Simulink Model of SEPIC Converter

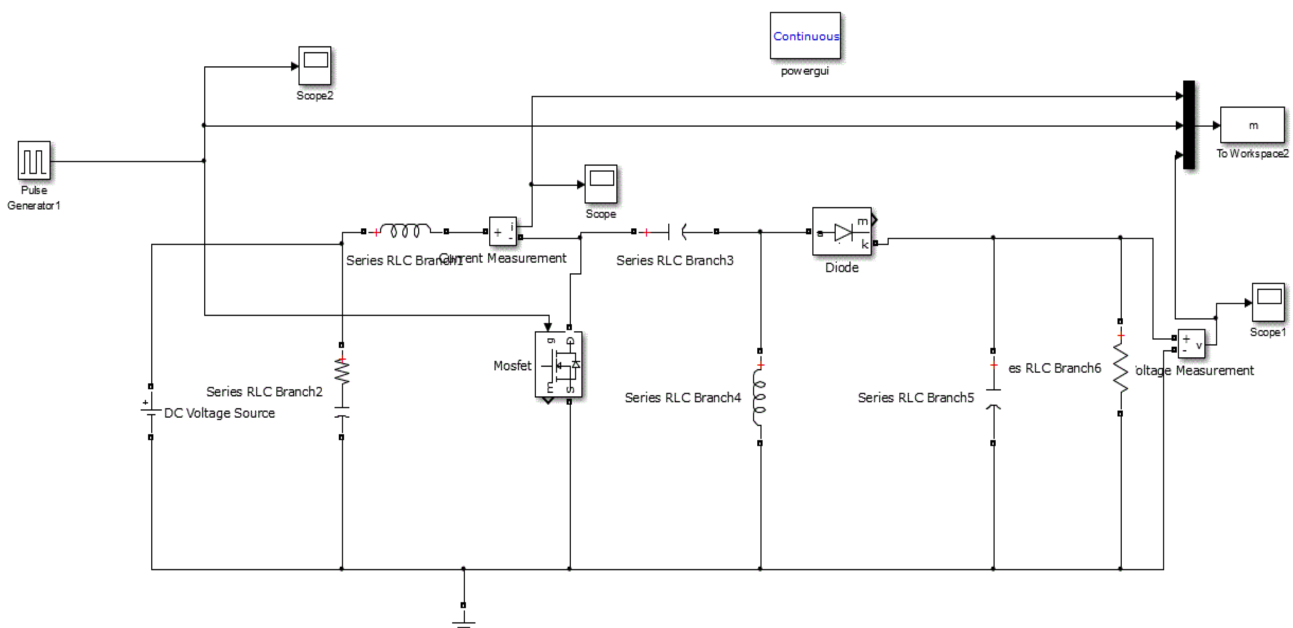

Figure 7 Simulink model of SEPIC converter

SEPIC converter is designed using mat lab Simulink shown below for fixed value of duty ratio. Duty ratio given 50% basis observe inductor ripple and output voltage of SEPIC converter shown below.

2.2.1 Simulation Result

Output wave form result of SEPIC converter shown on the basis of 50% duty ratio. Here input voltage apply to SEPIC converter 10 Volt correspondingly output side voltage appear for 50% duty ratio is:

$$Vout = \frac{D}{I-D} * Vin = 10 \text{ volt}$$

Here output result appear in Simulink is also 10volt so this will confirm that model is working fine. Inductor current ripple is shown in output given below shows that switching frequency of SEPIC converter 50 KHz.

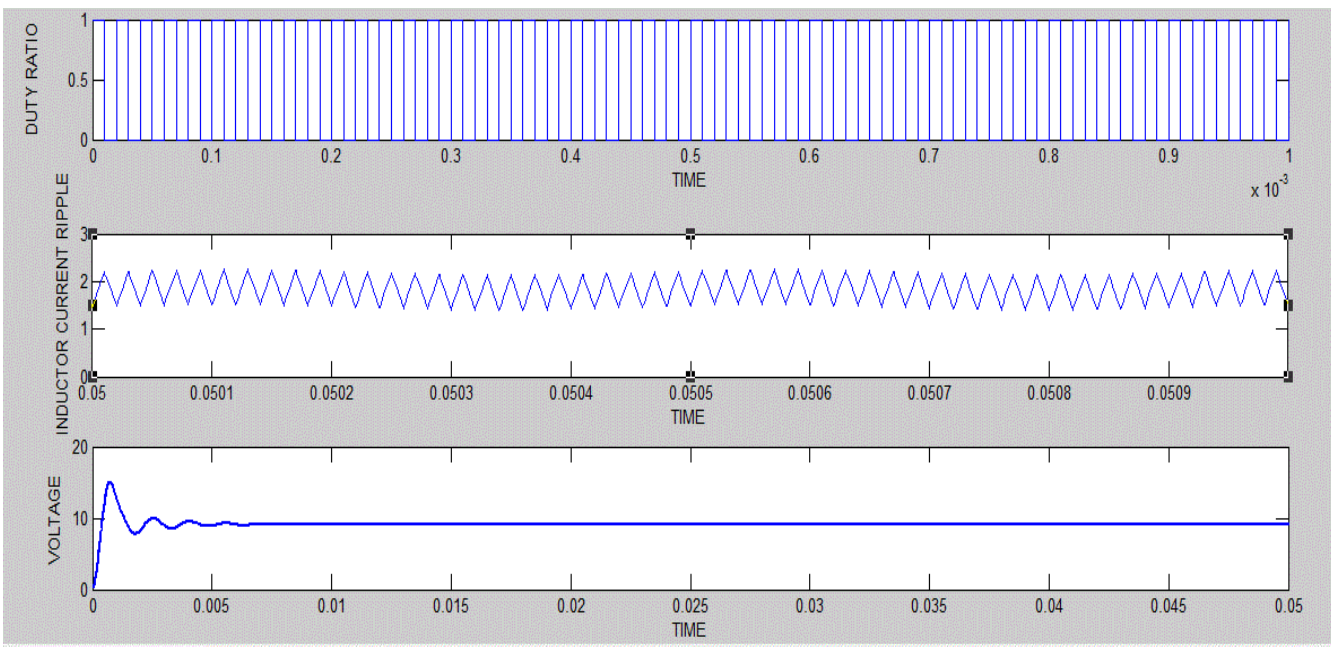

Figure 8 Output result Waveform of SEPIC converter

Chapter 3

Maximum Power Point Tracking

3.1. MPP TRACKING

As we know power conversion efficiency of solar module very low. To increase efficiency of solar module proper impedance matching require to increase efficiency of solar module. So different type of MPPT method developed by researcher in recent year. Every method has its advantage and disadvantage. MPPT algorithms are vary due to simplicity, efficiency, tracking speed, sensor required and cost. It is seen that the V-I characteristics of the solar module is nonlinear and extremely affected by the solar irradiation and temperature. To maximize the output power of solar module, it has to be operated at fixed value of load resistance. This require a separate power converter circuit for the MPPT. In our design, a SEPIC type DC–DC converter is used to extract the maximum power from solar module. Following algorithms for maximum power point tracking are listed below.

3.2. MPPT METHOD

Method used for MPPT are listed below:-

- Fractional open circuit voltage MPPT
- Fractional short circuit current MPPT
- Perturb and observe (P&O) MPPT
- Incremental conductance (INC) MPPT

3.2.1 Fractional open circuit voltage MPPT

Fractional open circuit (FOCV) fast and simple way of MPPT tracking. This algorithm not able to track exact maximum power point. Reason is that when irradiation level and temperature of module changes correspondingly MPP point change but this algorithm work on fixed value of voltage at MPP. This algorithm work on principle that voltage at MPP is nearly equal to open circuit voltage of module by factor N.

$$Vmpp \cong N * Voc$$

Where N is fixed and its value getting from data sheet of PV module. Value of N basically braying from .68 to .80 that depend on type of module used. Fractional open circuit voltage only require sensing of panel voltage that also we can sense by using simple voltage divider circuit across the panel. So fractional open circuit basically require no voltage sensor by using voltage divider circuit we can directly sense module voltage and apply to microcontroller. So we can conclude that implementation cost of fractional open circuit quit low but it is not capable for tracking exact MPPT.

3.2.2. Fractional short circuit current MPPT

This method also work on same principle of fractional open circuit voltage (FOCV). Similar to (FOCV) it is also not capable to track exact MPPT because it is also work on fixed value of current. Imp not change according to irradiation level and temperature changes.

$$Imp \cong N * Isc$$

Where value of N calculated according to data sheet of panel. Value of N normally vary from .82 to .94 that is depend on type of panel used. Fractional short circuit current (FSCC) require sensing of panel current. Current we cannot sense directly across the panel so current sensor is require to sense panel current. Generally hall effect based current sensor are used for MPP tracking due to its accuracy and transient response that use of current sensor make system cost effective. So we can conclude that implementation cost of fractional short circuit high and it is not capable for tracking exact MPPT.

3.2.3. Perturb and Observe (P&O) MPPT

Perturb and observe (P&O) is one of the famous algorithm due to its simplicity used for maximum power point tracking. This algorithm based on voltage and current sensing based used to track MPP. In this controller require calculation for power and voltage to track MPP. In this voltage is perturbed in one direction and if power is continuous to increase then algorithm keep on perturb in same direction. If new power is less than previous power then perturbed in opposite direction. When module power reach at MPP there is oscillation around MPP point. Flow chart of P&O algorithm given below:

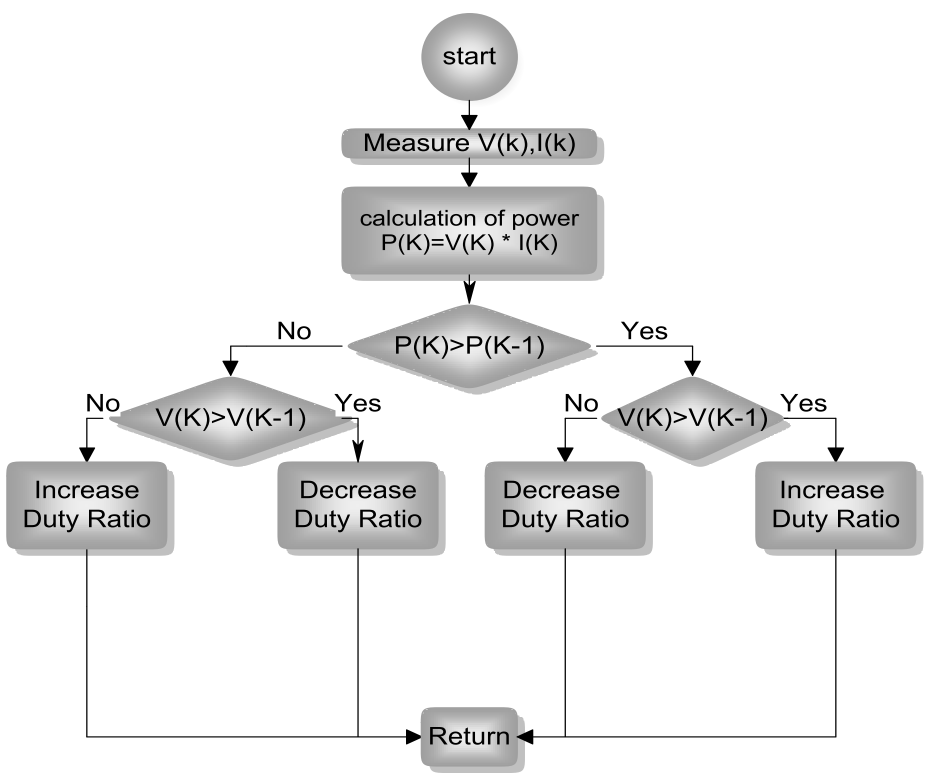

Figure 9 Flow chart of Perturb and observe algorithm

3.2.4. Incremental Conductance (INC) MPPT

In this technique, the controller measures incremental change in module voltage and current to observe the effect of a power change [1]. This method requires more calculation but can track fast than perturb and observe algorithm (P&O). Under abruptly change in irradiation level as maximum power point changes continuously, P&O receipts it as a change in MPP due to perturb rather than that of isolation and sometimes ends up in calculating incorrect MPP. However this problem get avoided by incremental conductance (INC).In this method algorithm takes two sample of voltage and current to maximize power from solar module. However due to effectiveness and complexity of incremental conductance algorithm very high compare to perturb and observe. Like the P&O algorithm, it can produce oscillations in power output. This study on realizing MPPT by improved incremental conductance method with variable step-size [6]. So these are two advantage of incremental conductance method. So in our implementation to achieve high efficiency this method utilize incremental conductance (dI/dV) of the photovoltaic array to calculate the sign of the change in power with respect to voltage (dP/dV). The controller maintains this voltage till the isolation changes and the process is repeated. Flow chart of incremental conductance is shown in Fig. 4.

As we know $P = V * I$

$$\frac{dP}{dV} = I + V\frac{dI}{dV}$$

At MPP point $I + V\frac{dI}{dV} = 0$

Left side of MPP $I + V\frac{dI}{dV} > 0$

Right side of MPP $I + V\frac{dI}{dV} < 0$

Because of the noise, of measurement's faults and the quantification, the condition $I + V\frac{dI}{dV} = 0$is rarely satisfied, therefore in steady state, the system oscillate nearby the MPP. To overcome this problem we introduce a new parameter e consider as:-

$$I + V\frac{dI}{dV} \leq e$$

Incremental Conductance flow chart for SEPIC converter. The amplitude of oscillation decrease by increase value e. In this paper e is chosen as .005 on the basis of trail an error procedure.

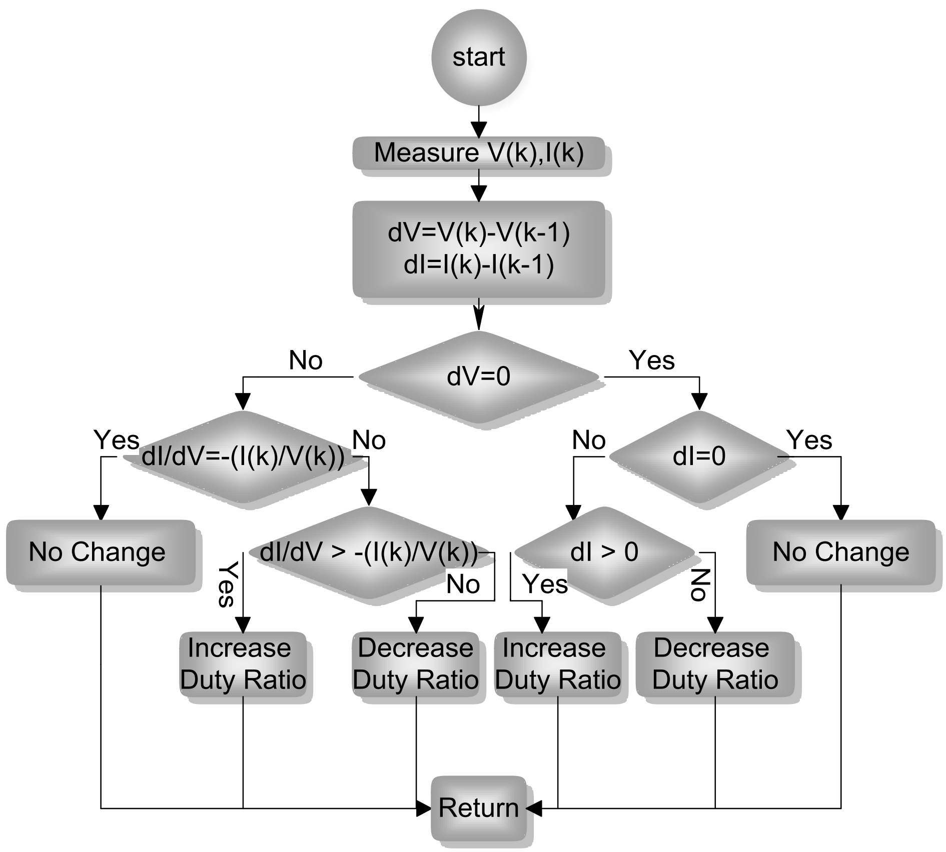

Figure 10 Flow chart of incremental conductance algorithm

Simulink Model of MPPT Control

A simulation model is develop using mat lab Simulink shown in Fig. 9, which shows PV module electric circuit, SEPIC converter and MPPT algorithm converter component are chosen according to the value specified in chapter 2. The PV module is modeled using electrical characteristics to provide the output current and voltage of the PV module specified in chapter 2. PV module connected to SEPIC converter and MPPT control simultaneously. Duty cycle adjusted incremental conductance algorithm running inside Arduino microcontroller. System tested with two different irradiation level whose I-V characteristic show in chapter 2.

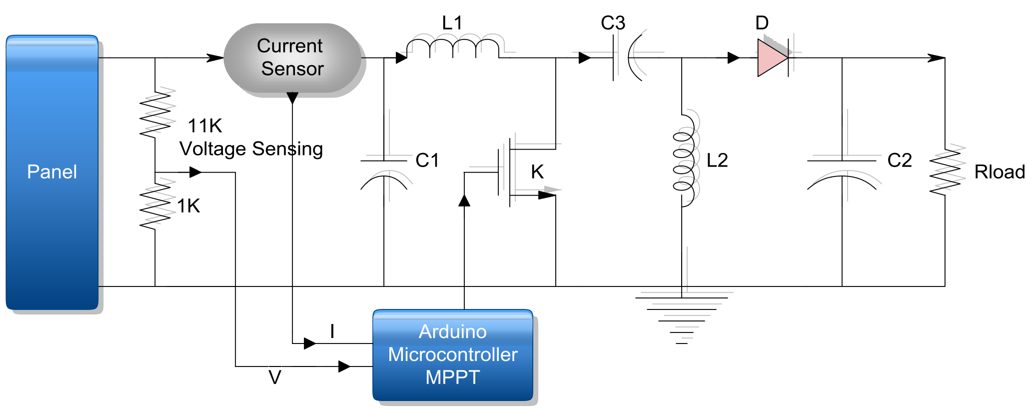

Figure 11 MPPT Tracking

3.3. Simulation Result

To test the system operation irradiation is varying between two levels, temperature is kept constant at 300 Kelvin. The performance of incremental conductance varies according to incremental step size and the value of parameter e chosen. A large step size may increase the tracking speed but at the same time the oscillation around MPP increase. Therefore it is important to compromise between tracking speed and the oscillation. In implementation of incremental conductance step size of the duty cycle is chosen to be 1% and the value of e has taken .001 for better tracking performance. Fist irradiation level 270 w/m^2 at MPP point power given by Simulink model 5.7 watts shown in Fig. 13. This result also compare with PV characteristic obtain in chapter 2. Irradiation level now change to 580 w/m^2 at MPP point voltage increase slightly but current increase by large value power given by module at MPP 11 watt which is shown in Fig. 14. To track MPPT point three step duty ratio change also observed shown in Fig 15. To verify the functionality and performance of Simulink model result shown in Fig. 13 and 14 compare with PV characteristic obtain with different irradiation level shown in chapter 2. Result obtain confirm that designed Simulink model working correct.

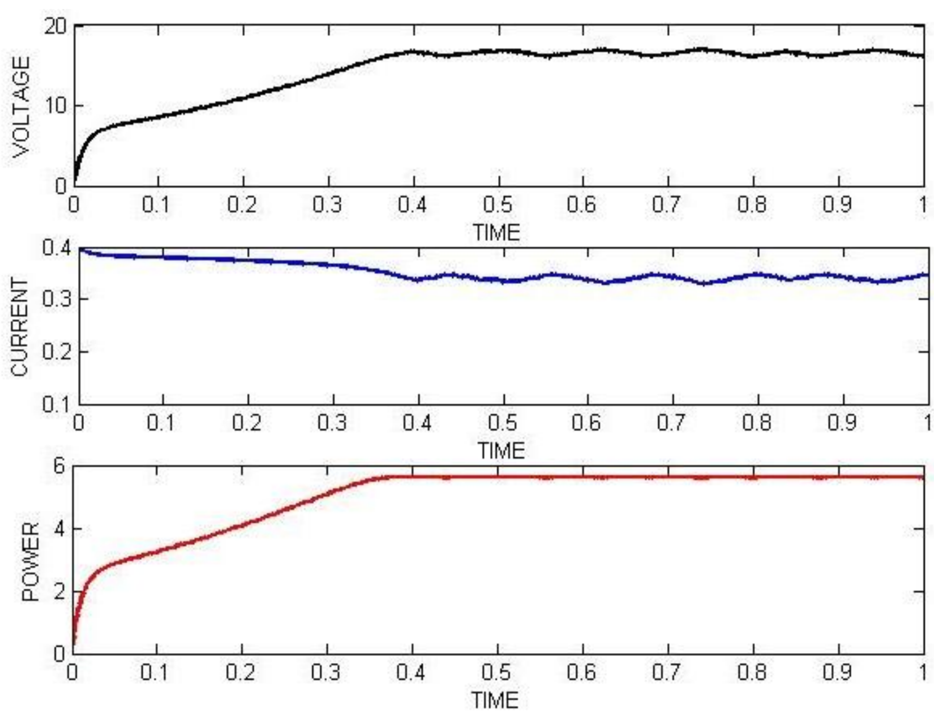

Figure 12 Simulation result at 270 w/m2

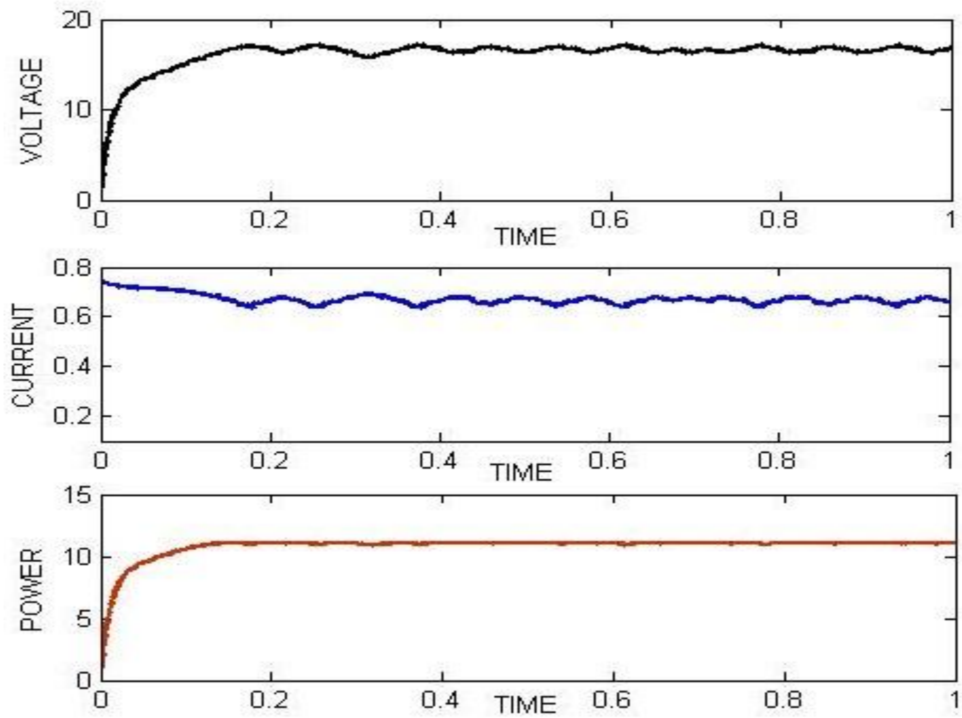

Figure 13 simulation result at 580 w/m 2

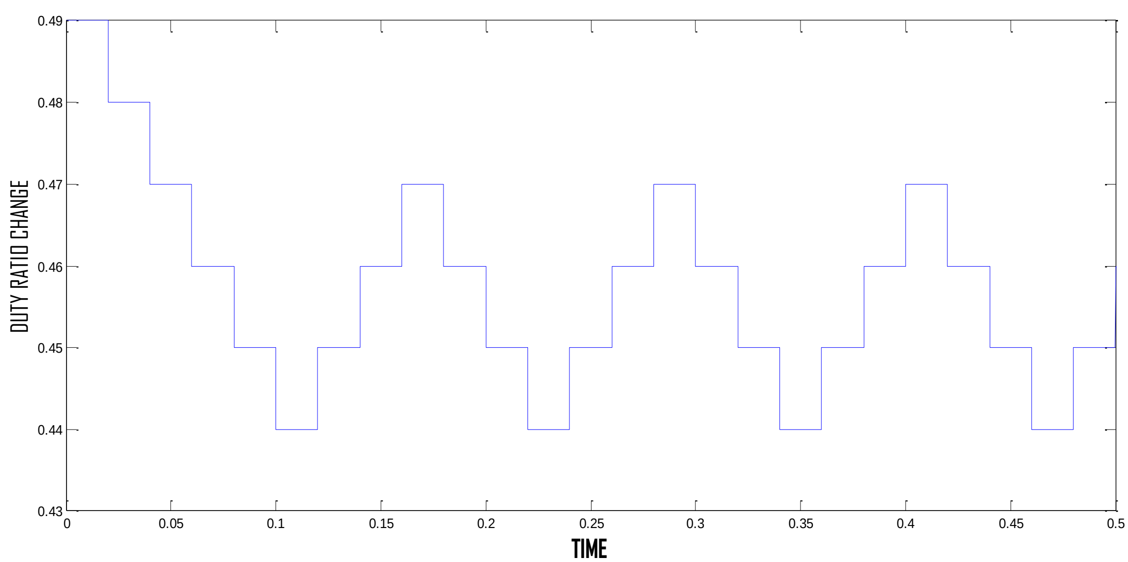

Figure 14 duty ratio changes at MPPT

3.4. Experimental Setup for MPPT Tracking

Figure 19, Show hardware setup for evaluating the proposed MPPT control method [3]. Voltage measurement is require at a point where PV module output connected input of SEPIC converter. This voltage indicated operating voltage of PV module. Current measurement is also require to indicate generated current of PV module at each operating point. Where current sensor connect between panel and switching DC-DC converter to maximize power from solar module. Voltage divider circuit is connected across panel to measure voltage given to Arduino microcontroller. Control algorithm check input voltage and current of the panel to maximize the power control procedure shown in chapter3.

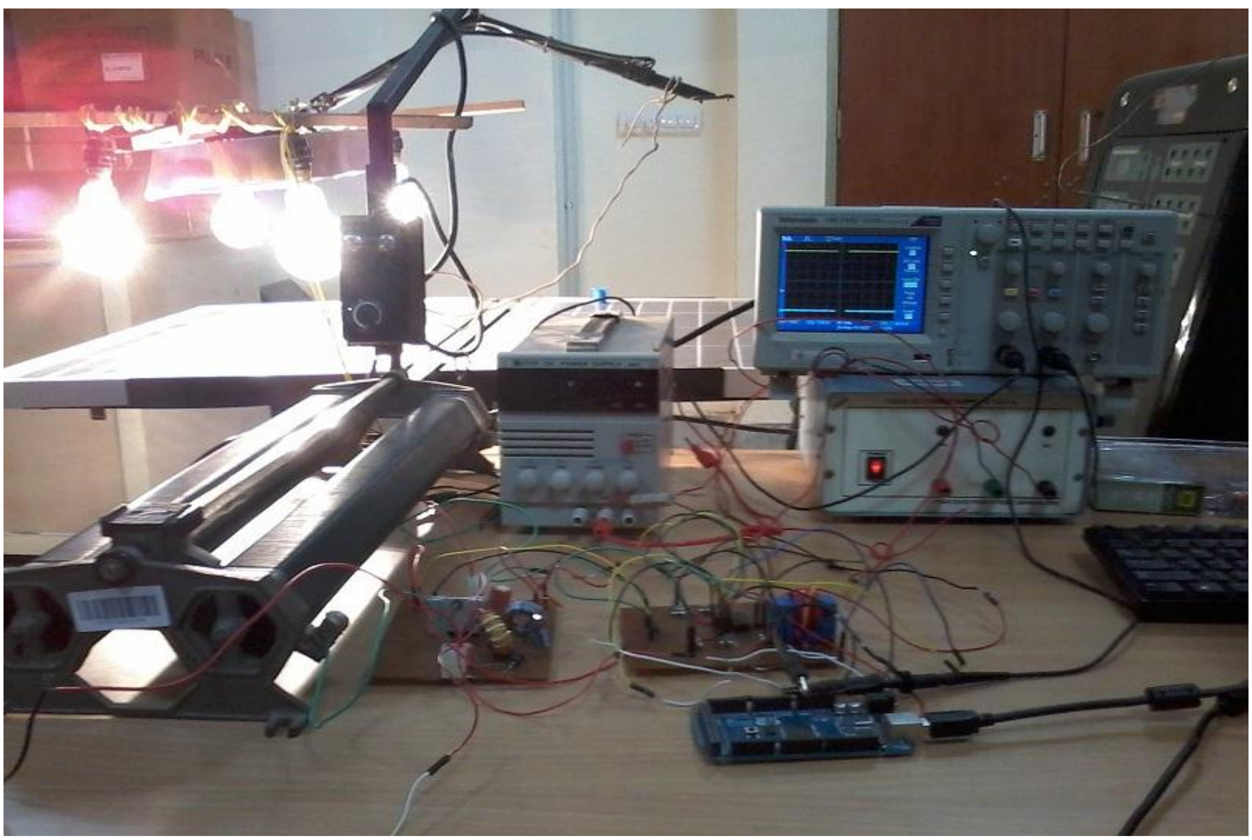

Figure 15 Experimental Setup

3.5. Experimental Result for MPPT

Fixed step size incremental conductance MPPT algorithm using SEPIC converter has been tested with LEM current sensor. From the results acquired during hardware experiments, it was confirmed that, with a well-designed system including a proper converter and selecting an efficient and proven algorithm like incremental conductance (INC) and perturb and observe (P&O) current sensor gives correct result of MPPT.

3.5.1 Experimental Result with 270 w/m^2

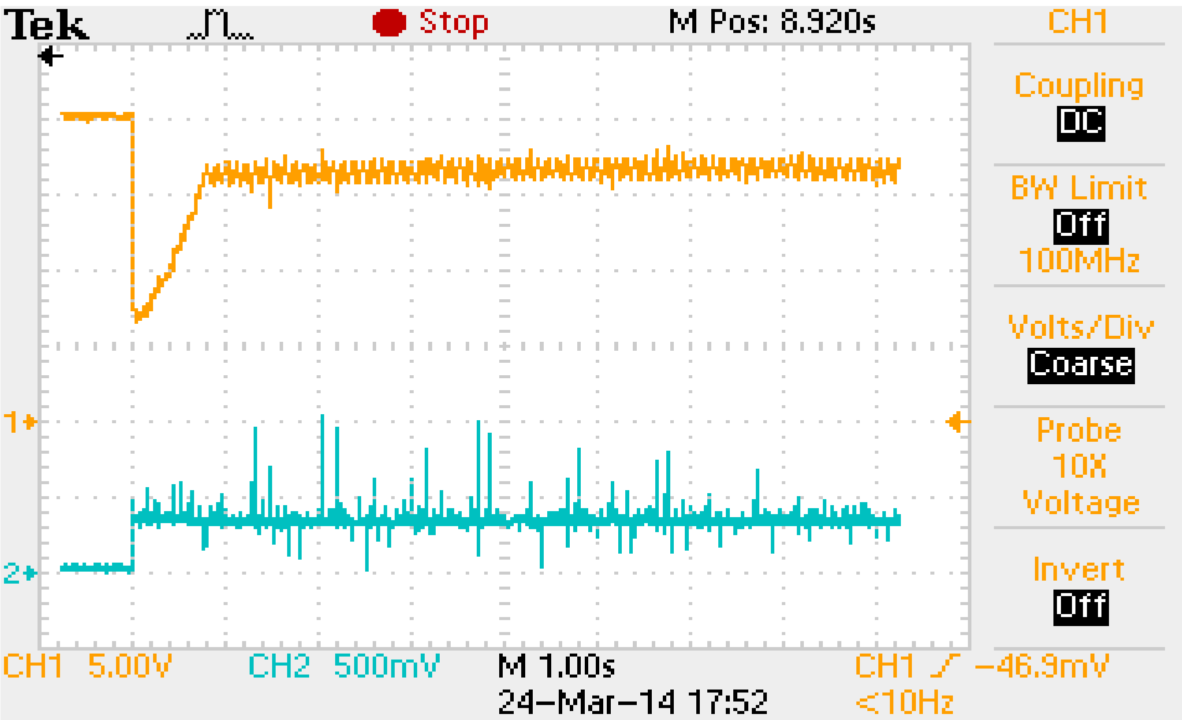

Figure 16 MPPT with LEM current sensor 270 w/m^2

3.5.2 Experimental Result with 580 w/m^2

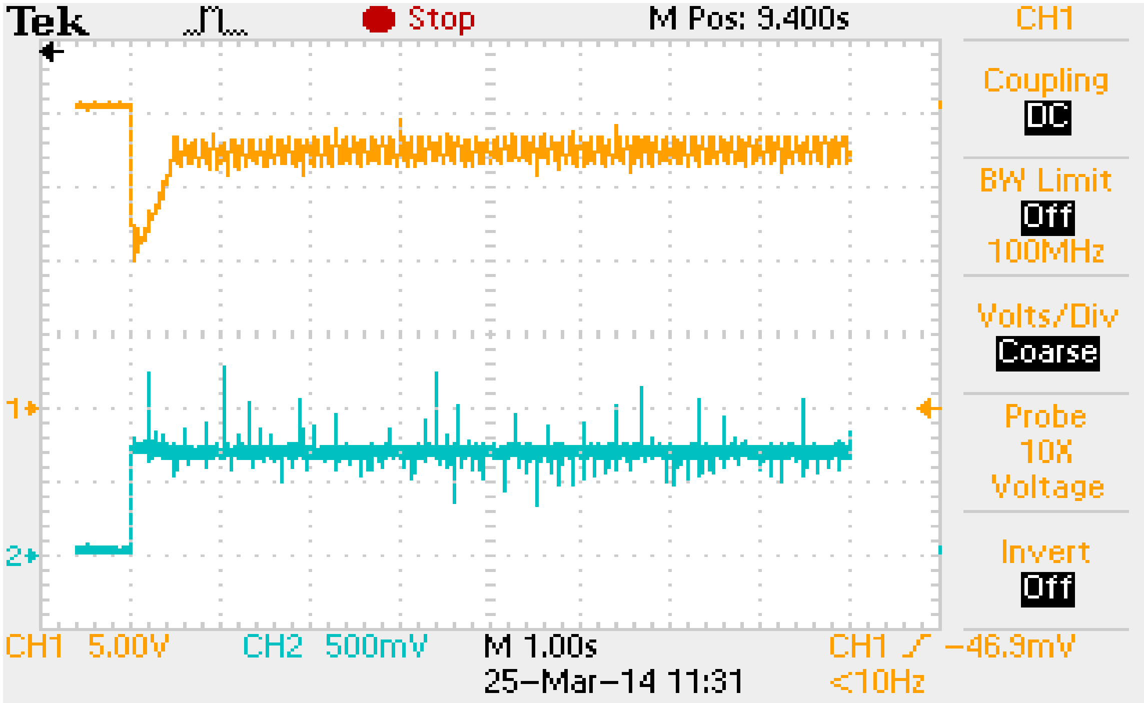

Figure 17 MPPT with LEM current sensor 580 w/m2

To test the system operation irradiation is varying between two levels, temperature is kept constant at 300 Kelvin. The performance of incremental conductance varies according to incremental step size and the value of parameter e given in section four [9]. A large step size may increase the tracking speed but at the same time the oscillation around MPP increase. Therefore it is important to compromise between tracking speed and the oscillation. When there is no gate pulse given by Arduino microcontroller module operating around an open circuit voltage (Voc) before connecting the PV module to load through MPPT and current at this point given by module zero. In implementation of incremental conductance step size of the duty cycle is chosen to be 1% and the value of e has taken .001 for better tracking performance. Fist irradiation level 270 w/m^2 when PV module connected to the MPPT circuit, it does not operating at open circuit voltage anymore and voltage drop to a new point instantly this new operating point depends on load impedance. In order to move new operating point to MPP, the control follow incremental conductance(INC) algorithm with Arduino microcontroller at MPP point power given by module 5.7 watt which is shown in

Figure 17. Irradiation level now change to 580 w/m^2 at MPP point voltage almost same and current increase by large value power given by module at MPP 11 watt which is shown Figure in 18. To verify the functionality and performance of hardware result is also compare with simulation shown in Figure 13 and Figure 14 in both cases same power has given by module in equivalent condition result confirm that experimental result obtain at two different irradiation level good designed system working fine.

Chapter 4

Battery Charging

4.1 BATTERY CHARGINGMETHOD

Battery life and performance are highly depends on method of charging. So optimal charging pattern is require to increase lifespan of battery with less charging time. To charge lead-acid battery safe, faster and full charging, the manufacture recommended charge lead acid battery with four charging step [2] that are called :

(1) Trickle charging

(2) Constant current charging

(3) Constant voltage charging

(4) Float charging

Battery Charging Stages

4.1.1 Trickle Charging (T1 To T2)

This step of charging used when battery enter in its typical discharging capacity. When battery voltage below then its critical voltage (V_T), battery enter in trickle charging stage. This voltage V_T is defined by manufacture. In this situation battery should charge by small value of current that is defined by I_T that has typical value of C/100 where C is defined as normal battery charging capacity with 10 hours of charging process. This small value of current applied up when battery voltage reaches to that critical voltage (V_T). If we not use this step of charging and charge battery with its normal charging capacity in this situation battery voltage suddenly increase to its open circuit voltage (V_{OC}) and battery is not charge to 100% SOC. So in this situation we cannot proceed next charging step and battery not charge with its full charging capacity.

4.1.2 Constant Current Charging (T2 To T3)

After fist charging step when battery voltage reaches to its critical voltage (V_T) now charging switch in to constant current region. In this region battery charge with maximum charging current I_C without any water losing. In this step of charging panel working at MPPT and supply maximum charging current to battery until battery voltage reach maximum value of overcharging voltage, defined by Voc which is specified by manufacturers. In this stage of charging battery have charge 80% SOC but there is still charging require to reach SOC 100%. So we have switch next step of charging that is called constant voltage charging.

4.1.3 Constant Voltage Charging (T3 To T4)

In this stage of charging output voltage of SEPIC converter regulate around over charging battery voltage (V_{OC}). That is achieved by sensing output voltage of SEPIC converter and compare that voltage with overcharging (V_{OC}) of battery try to operate panel accordingly. In this region battery charge up to charging current of battery fall below reestablished value of I_{OCT} and voltage stay in the value of Voc. Here value of I_{OCT} is 10% of Ic. In this region battery charge up to 100% of SOC.

4.1.4 Float Charging

This stage of charging used to avoid overcharging. During constant voltage charging stage battery charge up to 100% of SOC but it self-discharge after certain interval of time. In this stage battery voltage decrease due to self-discharge when battery voltage fall below .9 V_{OC} then this stage execute. So to remove self-discharging we have apply certain voltage after fixe interval of time to avoid self-discharging.

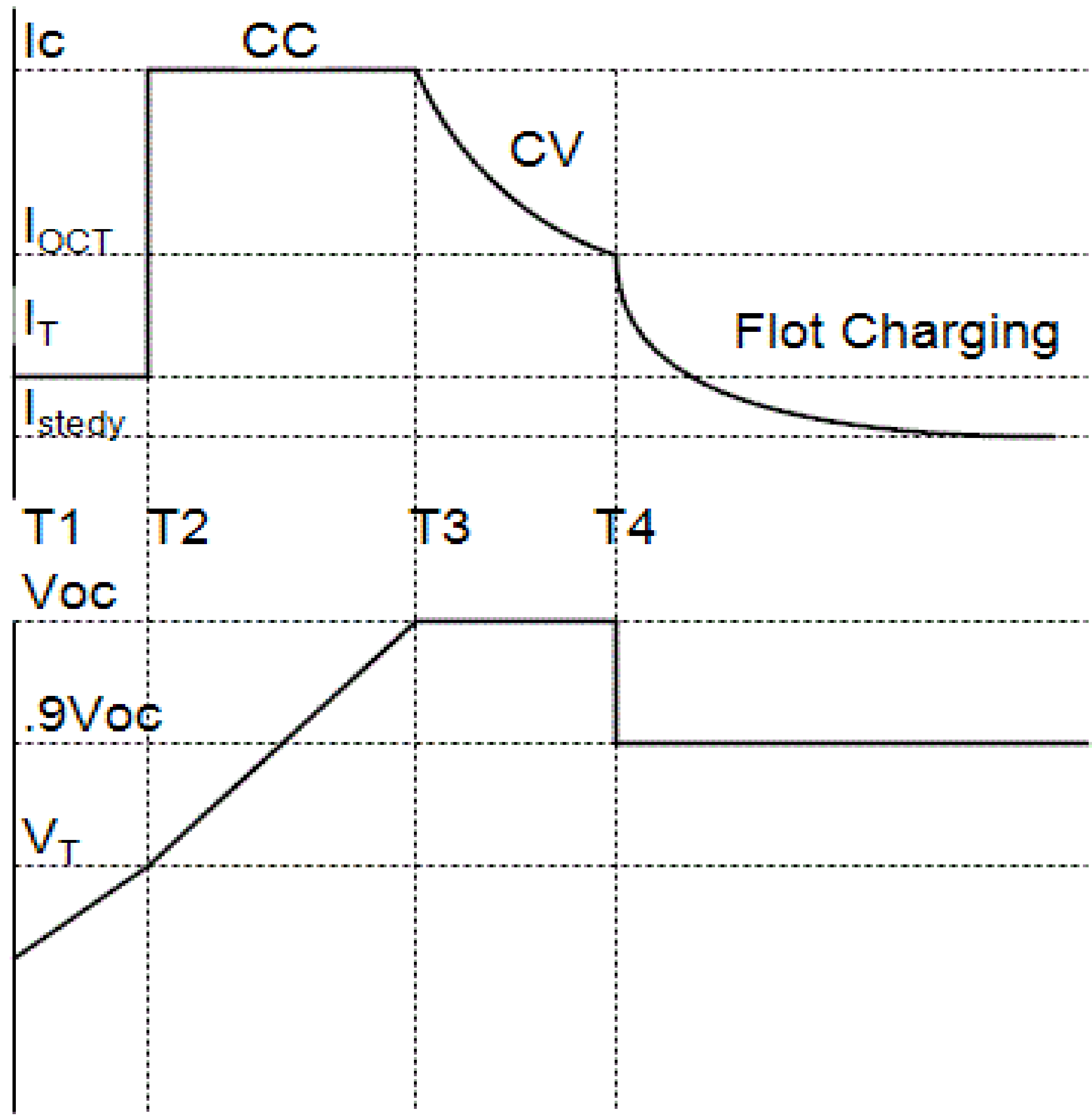

Figure 18 Battery Charging Step

4.2. Battery Charging Model

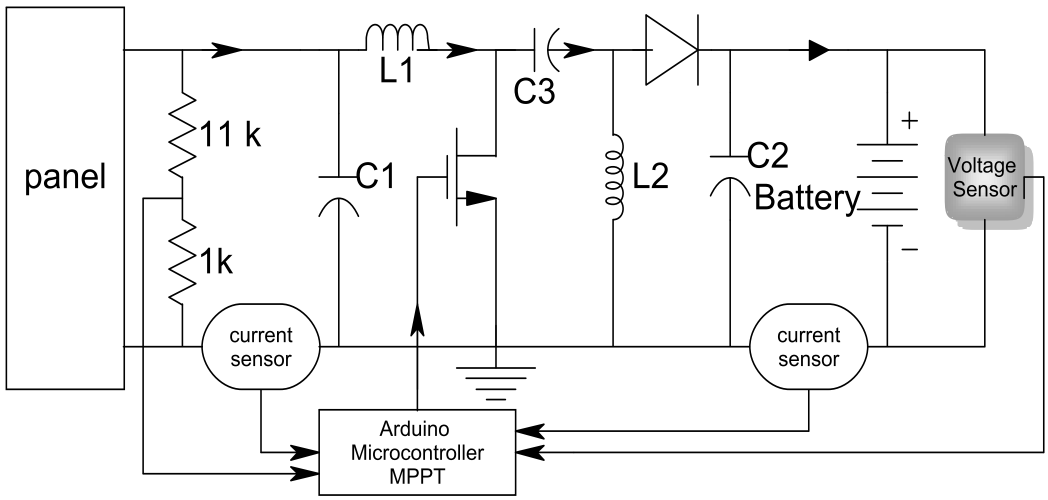

Figure 19 Battery Charging Model

4.3. Battery charging Result

When battery SOC below than 80% battery charge in constant current region. In constant current region module deliver maximum power to battery. Power absorbed from PV module 11 watt thus PV module operate around MPP.

A constant voltage charging region comes when battery SOC more than 80% in this region module is not operating at MPP. So that charge transfer to battery slow compare to constant current charging. Fig. shows that in constant voltage charging region current passing to battery .6 ampere. In this charging stage output voltage of SEPIC converter sense try regulate around over charging battery voltage (V_{OC}). This step of charging is used up to when battery overcharging limit not reached.

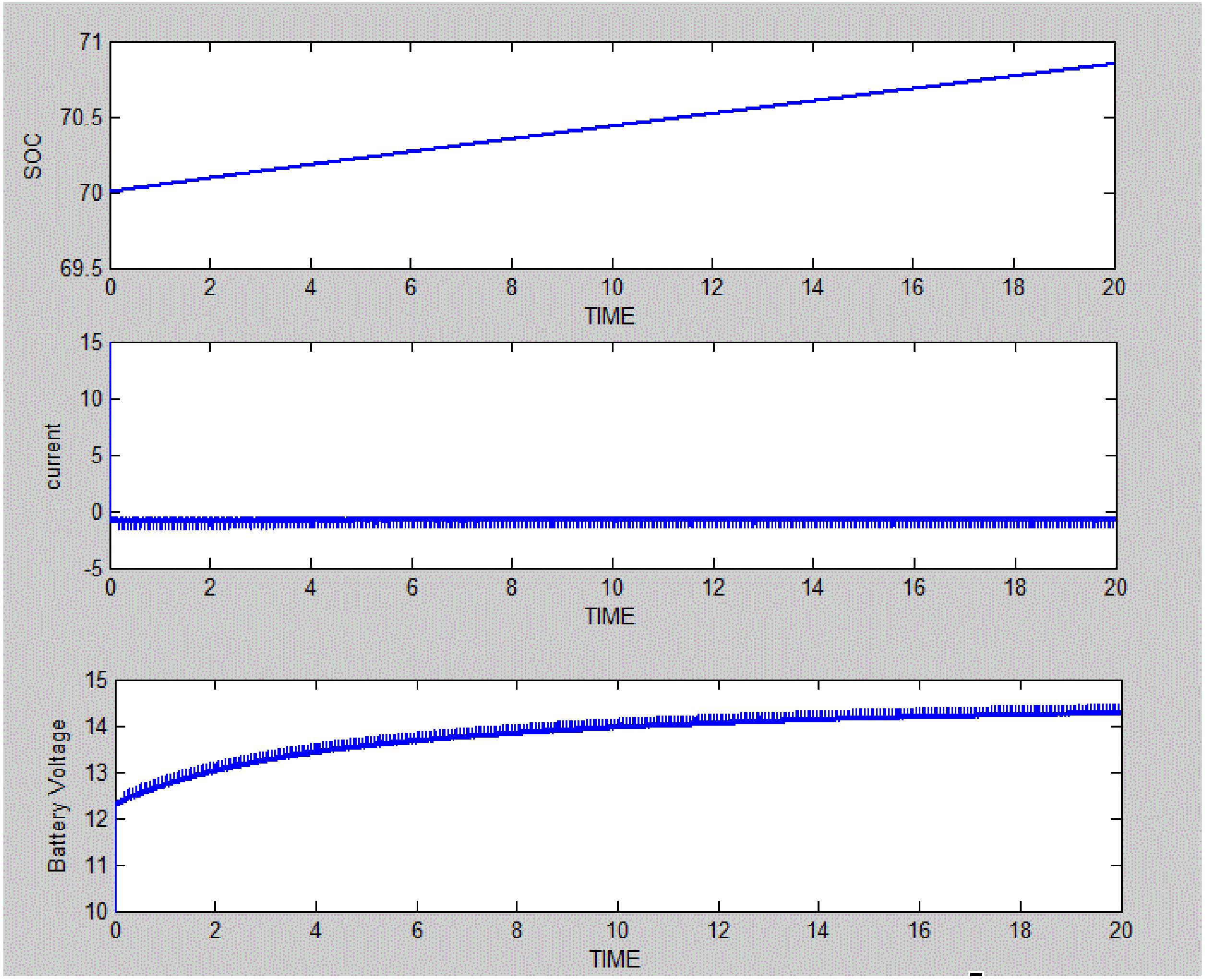

Figure 20 Battery Charging Result

Chapter 5

Conclusion And Future Scope

5.1. Conclusion

This method presented here control lead acid battery charging faster and safe with less charging time. The control algorithm execute INC method allow module to operate at maximum power point according to solar irradiation, when battery SOC low during this time maximum charge transfer from photovoltaic panel to battery. This charging pattern increase efficiency of power transfer comparison to other method and assure fast, safe and complete lead acid battery charging process with full SOC. The SEPIC converter used for implementation have advantage because it is easily adapt any PV output voltage according to battery condition. From the results acquired during hardware experiments, it was confirmed that, with a well-designed system including a proper converter and selecting an efficient and proven algorithm gives acceptable efficiency level of the PV modules.

5.2. Future Work

Improvement of this project can be made by charging lead acid battery with all four charging step that are: trickle charging, constant current charging, constant voltage charging and float charging. For future work the complete charging process should be analyzed to compare with another system working without (INC) MPPT algorithm [8].From the preliminary results it is expect that the charging process using the MPPT algorithm will be faster.

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